Cellulose Fibers as a Trendsetter for the Circular Economy that We Urgently Need

Martin A. Hubbe and Dhanalekshmi Savithri

Picking up a discarded can or bottle and placing it in a recycling bin may seem like a very small step to take in the direction of making a better world. The scope of benefits that might accrue, by combining many such steps, and making careful plans, was highlighted in a recent Waste to Advanced Resources Matter (WARM) workshop hosted at this university. As shown during the discussions at the workshop, those who are deeply involved with issues of waste management, climate change issues, and care for our planet already know the "broad brush" answers regarding what needs to be done. Now is the time for action in implementing efficient and widespread recovery of valuable materials and energy from what we presently throw away.

DOI: 10.15376/biores.19.2.2007-2009

Keywords: Recycling; Reuse; Waste to energy; Waste to value; Carbon reduction; Advanced materials

Contact information: Department of Forest Biomaterials, College of Natural Resources, North Carolina State University, Campus Box 8005, Raleigh, NC 27695-8005, USA;
Corresponding author: hubbe@ncsu.edu

Recycling Rates

Big changes throughout the economy will be required to meet society's goals for reducing carbon emissions. Motivations to meet those goals can be expected to increase as the effects of global warming become increasingly obvious. Recycling – allowing second and further usages of materials – is expected to play an important role in such efforts. In principle, it takes much less energy to reuse the material in manufactured items rather than to process new material obtained from natural sources. Relative to other manufactured materials, the cellulose fibers within paper have achieved star status. In particular, the fibers present in corrugated boxes have achieved a recycling percentage of 93.6% in the U.S. (AFPA 2022). When considering all grades of paper, the recycling rate still achieved a respectable level of reuse, 67.9%. By contrast, the recycling of plastics in the US has been estimated to be in the range 20% to 30% (Holt *et al.* 2023). Even in Europe, where efforts have been made to reduce plastic waste, only about 26% of those wastes are being formed back into plastic items (Datta and Kopczynska 2016). In Austria, 55% of discarded aluminum has been recycled, though it has been projected that this number could be increased to either 72% or 94% by different advanced technology options at waste recovery sites (Warrings and Fellner 2021). Given the energy-intensive processes involved with the production of aluminum (Shen and Zhang 2024), even the 55% number can be regarded as a disappointment. And whereas paper products mostly biodegrade if they are cast off in the environment, plastics and aluminum will persist for thousands of years (Zambrano *et al.* 2019).

Looking Forward

Our academic department at North Carolina State University has a long and deep history of doing research related to paper and wood products. This includes not only research into paper recycling, but also the more effective and imaginative usage of the so-called "urban wood," which can serve as the material for crafts and specialty products (Kropat *et al.* 2020). A few years ago, the department updated the focus of our efforts related to wood products, instituting a new program in Sustainable Materials Technologies.

To more fully achieve sustainability goals, as noted earlier, it will be necessary to achieve much higher reusage percentages, not only of paper, but of a broad range of materials that arrive each day at solid waste facilities. This was the topic of an inaugural "Waste to Advanced Resources Matter" (WARM) workshop that was held at North Carolina State University on November 15, 2023. Through the leadership of Dr. Lokendra Pal, from our department, a step toward global partnership was initialized *via* the WARM workshop. The participants in the workshop were heavily represented by "doers," rather than just scholars. Thus, the WARM participants included leaders from industries, municipalities, national laboratories, federal and state agencies, non-governmental organizations, and universities. The two-day workshop consisted of presentations and numerous break-out group discussions on diverse perspectives from people running solid waste facilities to research and technology professionals regarding the challenges of Municipal Solid Waste (MSW) management. The focus groups formed discussed strategies and studies conducted for implementing waste-to-products initiatives such as handling/sourcing; characterization/separation; pre-processing/homogenization; and utilization/valorization. These steps would form the foundations for the four pillars of sustainability *viz.*, human, social, economic, and environmental.

Waste management has become a major international issue. Waste production is directly related to human activities. Rapid economic development has fueled the need for proper waste management. The U.S and most other countries still fall behind in this key issue, disposing over 50% of generated waste in landfills (EPA 2017). This landfilling of waste has the capability to pollute the atmosphere and nearby water sources, posing serious health and safety repercussions for local individuals. Foreign countries such as Japan have become very advanced and responsible in the disposal of waste, sending only 1.5% to landfills (Sun *et al*. 2018).

Seeing how waste generation is predicted to approach 2.2 billion tons by 2025, there must be drastic improvements in the way waste is managed to combat the extreme environmental consequences associated with it. In order to increase landfill diversion, appropriate action must be taken at the global, national, regional, and local levels (Tiseo 2021). The WARM participants had an opportunity to tour the MRF/South Wake SWM Landfill facilities. The organizers of WARM workshop envisioned this idea, as action taken at any level would benefit the environment. Municipal waste can be recycled and recovered (Yang *et al*. 2023). At the college level, in our institution we have implemented a new way of separating office waste, as recycling/composting/land fill, *etc*. A high-tech project, involving "AI-driven Smart MSW Management System" to identify and characterize various organic fractions of MSW has been developed by Pal group. The success of this project will contribute significantly to the sustainable utilization of solid waste as renewable carbon resources.

Clearly, the WARM workshop has provided insight into new research directions to be adapted for the development of pathways for MSW as a useful material, allowing it to be transformed into feedstock for the biorefinery and production of high-value products.

REFERENCES CITED

AFPA (2022). American Forest & Paper Association. "Paper and cardboard recycling," as of this date showing data for 2022. https://www.afandpa.org/priorities/recycling; site visited January 22, 2024.

Datta, J., and Kopczynska, P. (2016). "From polymer waste to potential main industrial products: Actual state of recycling and recovering," *Crit. Rev. Environ. Sci. Technol.* 46(10), 905-946. DOI: 10.1080/10643389.2016.1180227

EPA (2017). *National Overview: Facts and Figures on Materials, Wastes and Recycling*. Retrieved from https://www.epa.gov/facts-and-figures-about-materials-waste- and-recycling.

Holt, J. R., Bui, D. P., Chau, H., Wang, K. T. Y., Trevisi, L. M., Jerdy, A. C. R., Lobban, L., Crossley, S., and Feltz, A. (2023). "Development of an objective measure of knowledge of plastic recycling: The outcomes of plastic recycling knowledge scale (OPRKS)," *J. Environ. Psychol.* 91, article 102143. DOI: 10.1016/j.jenvp.2023.102143

Kropat, M., Hubbe, M. A., and Laleicke, F. (2020). "Natural, accelerated, and simulated weathering of wood: A review," *BioResources* 15(4), 9998-10062. DOI: 10.15376/biores.15.4.Kropat

Shen, A.-X., and Zhang, J.-H. (2024). "Technologies for CO_2 emission reduction and low-carbon development in primary aluminum industry in China: A review," *Renew. Sustain. Energy Rev.* 189, article 113965. DOI: 10.1016/j.rser.2023.113965

Sun, L., Li, Z., Fujii, M., Hijioka, Y., and Fujita, T. (2018). "Carbon footprint assessment for the waste management sector: A comparative analysis of China and Japan," *Front. Energy* 12(3), 400-410. DOI: 10.1007/s11708-018-0565-z

Tiseo, I. (2021). "Generation and discards of municipal solid waste in the US 1960-2018," *Statista* 2021.

Warrings, R., and Fellner, J. (2021). "How to increase recycling rates. The case of aluminum packaging in Austria," *Waste Manag. Res.* 39(1), 53-56. DOI: 10.1177/0734242X20947161

Yang, S., Lang, R., Wu, M., Chen, H., and Li, Q. (2023). "Research progress and frontier of global solid waste management based on bibliometrics," *Environ. Dev.* 48, article 100922. DOI: 10.1016/j.envdev.2023.100922

Zambrano, M. C., Pawlak, J. J., Daystar, J., Ankeny, M., Cheng, J. J., and Venditti, R. A. (2019). "Microfibers generated from the laundering of cotton, rayon and polyester based fabrics and their aquatic biodegradation," *Mar. Pollut. Bull*. 142, 394-407. DOI: 10.1016/J.MARPOLBUL.2019.02.062